Perceived Floor Slipperiness in a Gait Experiment

Caijun Zhao
School of Safety & Environmental Engineering,Hunan Institute of Technology, Hengyang, PRC
Tel:18373410828,Email:zhaocaijun88@163.com
Ai-qun Liu
School of Safety & Environmental Engineering,Hunan Institute of Technology, Hengyang, PRC
Tel:13875772403,Email:89338723@qq.com
Lu Peng
School of Safety & Environmental Engineering,Hunan Institute of Technology, Hengyang, PRC
Tel:15211855435,Email:810949212@163.com
Faming Jiang
School of Safety & Environmental Engineering,Hunan Institute of Technology, Hengyang, PRC
Tel:15973404342,Email:185496578@163.com
Kai-Way Li†
School of Safety & Environmental Engineering,Hunan Institute of Technology, Hengyang, PRC
Department of Industrial Management, Chung Hua University, Hsin-Chu, Taiwan
Tel:+86-18374719969,Email:kaiwayli@qq.com

Abstract. Slips and falls are common. In this study, a gait experiment was performed. Three 6-m walkways were installed. The floors of these walkways were polished granite and ceramic walkways with different roughness levels. There were three floor surface conditions: dry, wet, and water-detergent solution covered. Two types of shoes were tested: rubber-soled and Ethylene-vinyl acetate (EVA)-soled. In addition, the lighting conditions included light and dark. For each trial, the subject stood before the walkway and gave a perceived floor slipperiness rating on a five-point scales from 1 extremely slippery to 5 not slippery at all. He, then walk through the walkway and stopped at the end of the walkway. The subject gave a perceived floor slipperiness rating again. In addition, he also gave a perceive sense of slipperiness (PSOS). The results indicated that floor (p<0.0001), surface condition (p<0.0001), and lighting condition (p<0.0001) were all significant on perceived floor slipperiness rating before the gait. The Duncan's multiple range test results showed that the perceived floor slipperiness ratings between the two ceramic walkways (4.47 & 4.33 for walkway 1 and 3) were not significantly different and they were significantly (p<0.05) higher than that (3.65) of walkway 2 (polished granite). Significance of the study was discussed.

Keywords: Floor Slipperiness; Perceived Floor Slipperiness Rating; PSOS

1. INTRODUCTION

Falls are one of the leading causes of death and injury in the workplace (Leamon and Murphy, 1995; Chang et al., 2001; Chiou, 2003; Li et al., 2006; Chang et al., 2011). In the UK, 152workers were killed in 2009 because of falling. This corresponds to a fatality rate of 0.5 per 100,000 workers.In the USA, slip and fall incidences accounts for 17% of all occupational incidences, 18% of all incidences in public spaces, and 20% of all incidences in residence. There are 0.25 to 0.3 millions injury/fatality cases because of slips and falls. The numbers of death associated with these cases were between 1200 to 1600. Anaverage workers' compensation cost per claim forsame-level falls of US$6745 has been reported (Washington State, 2004). In Taiwan, official statistics (CLA, 2008) showed that falling incidences have accounted for more than 15% of all job-related injuries and have been the third most common causes of occupational incidences. There were 115 construction worker killed in 2008 because of falling which corresponds to a fatality rate of 1.62 per 100,000 workers(CLA, 2009).

Floor slipperiness is regarded as one of the most important parameters in assessing the risk of slip and fall. It may be assessed using a friction measurement device (Li et al., 2006; Liu et al., 2010; Li et al., 2012; Li et al., 2013; Li et al., 2014; Chen et al., 2015), by measuring subjective response of human subject (Courtney et al., 2006; Courtney et al., 2010; Chang et al., 2011), or both (Hsu and Li, 2010). Information concerning walking behavior of human is of primary importance in developing ergonomic intervention in slip and fall prevention (Grönqvist et al.,2001; Courtney et al., 2006; Chang et al., 2001; Chang et al., 2011; Yu and Li, 2012). Tisserand (1985) indicated that there is a mental model of friction limits when a person is walking. The person revises the image of friction to organize information received and then adjusts the forces applied on the floor so as not to exceed those limits. Information from both visual perception and proprioceptive recognition to maintain bodily balanceare important for a safe walk (Leamon, 1992). Before stepping on the floor, a walker receives floor slipperiness information via visual perception. The person, then, revises the floor slipperiness information according to the proprioceptive sensation received in a gait. The person may not be able to revise friction information in time when an unexpected low friction appears which may result in a fall.

Scientific investigations on the relationship between perceived floor slipperiness and coefficient of friction (COF) have been reported. Scientists (Swensen et al.,1992) investigated subjective ratings and rankings of the slipperiness of steel beams. They reported strong correlation between the COF and subjective rating ($r \geq 0.75$).Subjective ratings of floor slipperiness with the COF ontested floorshad also been studied and a strong correlation (r=0.97)between the two measures has been reported (Grönqvist et al.,1993).

In a field study, Chang et al. (2004) collected subjective ratings of floor slipperiness from restaurant workers in Taiwan. Theycollected subjective floor slipperiness from restaurant workers in different working areas based on their perception during the lunch period service.The authorsfound a Spearman's correlation coefficient of 0.45 between the perceived floor slipperiness and the COF on the floors. A Spearman's correlation coefficient of 0.36 between the COF and perceived floor slipperiness from restaurant workers in the USAwas reported in a later study (Chang et al., 2006; Chang et al., 2008).

Cohen and Cohen (1994a) had subjects slid their barefoot on the test titles and comparethe slipperiness of these tiles with a standard tile(COF=0.5). They found disagreements between subjects' rankings and the COF values of the tiles. In a follow-up study, Cohen and Cohen (1994b) exposed their subjects to 10 walking surfaces. Their subjects looked at the floor, rated its perceived slipperiness (observed). Then, walked across the surface, and rated it again (experienced). For both the dry and wet surfaces, the difference between the "observed" and "experienced" ratings was not statistically significant. They claimed that the subjects estimated the slipperiness of a surface when observing it and then tended to confirm the estimations when they walked over it. This implied that prior observation could influence later experience in the perception of floor slipperiness.

Both floor slipperiness and floor roughness affect the occurrence of slipping and falling. Li et al. (2011) compared the perceived roughness and perceived floor slipperiness of five floors based on tactual sensations from different body segments for males and females. They found that females tended to give higher subjective ratings on both perceived roughness and slipperiness than their male counterpart. Their regression analysis results indicated that floor roughness parameter R_a is a better predictor in predicting both the perceived floor roughness and perceived floor slipperiness than the COF of the floor.

Both the studies of Cohen and Cohen (1994a) and Li et al. (2011) measured perceived floor slipperiness by asking their subjects sliding their foot on the floor. The two studies might have different results if their subjects were walking, instead of sliding the foot, on the floor. In addition, Cohen and Cohen (1994b) reported that there was no significant difference between floor slipperiness perceptions before and after a walk and claimed that prior observation could influence later experience in the perception of floor slipperiness. This is not always true. People do remedy their perception when they perceive changes in floor slipperiness (Leamon, 1992).

Discussions of the factors affecting the amount of adjustment in floor slipperiness perception in the literature are, however, rare.

Floor slipperiness, floor roughness, and shod conditions are all believed to have effects on the occurrence of slipping and falling during a gait. Perception of floor slipperiness and floor roughness are important measures in understanding the risk of slipping and falling (Li et al., 2011). The purposes of the study were to compare the perceived floor slipperiness before and after walking on the floor.

2. METHODS

A gait experiment was conducted in the ergonomics lab at Hunan Institute of Technology. The mean temperature and humidity were 17.2 ℃ and 74.7%, respectively.

2.1Human Subjects

Six male subjects participated in the experiment. Their age, stature, body mass, and length of lower extremity were 21.17yrs (±1.22), 168.67cm (±6.03), 60.17 kg (±6.63), and 85.70cm (±2.05, respectively. All the subjects read and signed an informed consent for theirparticipation in the experiment.

Table 1: Fundamental data for human subjects

	mean	Std	min	max
age (yrs)	21.1	1.2	19.0	22.0
Stature （cm）	168.7	6.0	163.0	180.0
body mass （kg）	60.2	6.6	52.0	72.0
leg length （cm）	85.7	2.0	83.6	89.5

2.2 Experimental Conditions & Factors

The experimental conditions included floor, floor surface, shoes, and level of illumination. There were three floors tested (see Figure 1). The first and the second floors were ceramic floors with different surface roughness and were termed ceramic floor 1 (C1) and ceramic floor 2 (C2). C1 had higher surface roughness than C2. The third floor was a polished granite floor. This one had the finest surface profile among all tested floor. Three 6-m walkways were prepared using each of these floors. A suspension rail was installed overhear to support a safety harness along the walkway to provide safety precaution for the gait.

The floor surface condition included dry, wet, and detergent-solution contaminated surface (simply detergent). For dry condition, clean dry floor surface was tested. The wet condition was that the floor was covered with tap water. The detergent-solution was prepared by mixing the detergent with water in the ratio of 1:30. The shoes condition included rubber soled shoes and EVA-soled shoes (see Figure 2). The illumination conditions in the lab included light and dark. The illumination was measured at 10 spots on the walk path on the floor using a TES1336A light meter. For light condition, the illumination was 306.8 (±183.0) lx. For dark condition, the illumination was 0.43 (±0.37) lx.

（a）C1 （b）granite （c）C2

Figure 1: Floors

（a）EVA-soled（b）rubber-soled

Figure 2: Shoes

2.3 Experiment Procedure

When the subject reported to the research personnel in the laboratory, his fundamental data were recorded. In light condition, the subject was requested to stand at the starting point in the walkway and wore the safety harness. For dark condition, the subject was waiting in a preparation room next door to the laboratory, the subject wore an eye mask before entering the lab. He was guided by a research personnel to the lab and to the starting point in the walkway. The subject then removed the eye mask wait for approximately five minutes for dark adaptation and continued the same procedure as in the light condition. The subject looked at the floor and gave a subjective rating of floor slipperiness before gait start. This rating was termed RFS_{before}. He walked at a speed following the sound of a metronome toward the end of the walkway and stopped. The metronome pace of the metronome was 100 per minute. The subject gave a subjective rating of floor slipperiness afterthe gait.This rating was termed RFS_{after}.In addition, a perceived sense of slip (PSOS) rating was also collected.

2.4 Dependent Variables

In the experiment, the following dependent variables were collected: RFS_{before}, RFS_{after}, and PSOS. A five-point scale was adopted for both the RFS_{before} and RFS_{after}: from 1 extremely slippery to 5 not slippery at all. The PSOS was composed of the following four questions(Chiou et al., 2000):

1) How much did you feel yourself slip?
2) Did you have any difficulty in maintaining balance?
3) Did you feel at any time that you would slip?
4) What would you say was the overall difficulty of this task?

Each of the questions required a five-point responses from 0 (not at all) to 2 (a lot) with an increment of 0.5. The total point was obtained by adding the ratings from these four questions.

2.5 Experiment Design & Data Analysis

Afactorial randomly block design experiment was performed. The illumination condition was the block. The total trial was 216 (6 subjects × 2 shoes × 3 floors ×3 surfaces ×2 illumination conditions). Analysis of variance (ANOVA) was performed. Duncan's multiple range tests were performed for factors with more than two levels if the main factor reached the significance level of 0.05. The statistical analyses were performed using the SAS® 9.0 software.

3. RESULTS

3.1 Descriptive Statistics

Figure 3 shows the RFS_{before} under floor, surface, and illumination conditions. Figure 4shows the RFS_{after}.under floor and surface conditions. Figure 5 shows the PSOS under shoes, floor, and surface conditions.

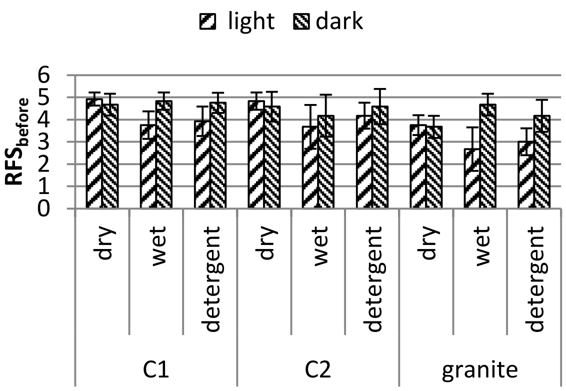

Figure 3: RFS_{before}. under floor, surface, and illumination conditions

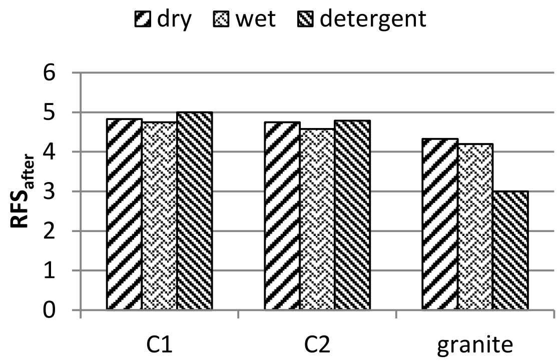

Figure 4: RFS_{after}.under floor and surface conditions

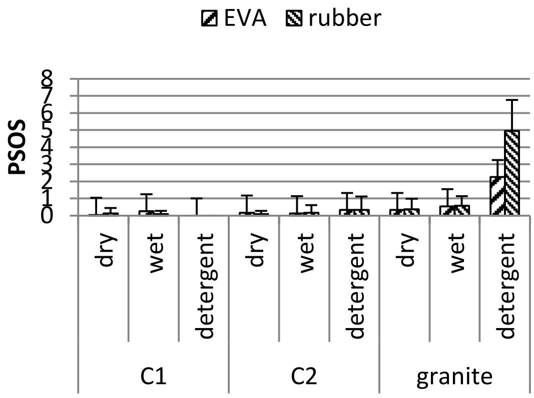

Figure 5: PSOS.under floor, surface, and shoes conditions

3.2 Analyses of Variance

The ANOVA results of the RFS_{before}indicate that the following effects were significant: floor (p<0.0001), surface (p<0.0001), illumination (p<0.0001), floor × illumination (p<0.01), and surface × illumination (p<0.0001). The effects of shoes were not significant. The Duncan's multiple range test results for the floor, surface, and illumination conditions are shown in Table 2, 3, and 4.

Table 2: Duncan's multiple range test results for RFS_{before} of floor conditions

Floor	Mean RFS_{before}	Duncan's grouping
C1	4.47	A
C2	4.33	A
Granite	3.65	B

Table 3: Duncan's multiple range tests results for RFS_{before} of surface conditions

Floor	Mean RFS_{before}	Duncan's grouping
Dry	4.40	A
Wet	4.09	B
Detergent	3.96	B

Table 4: Duncan's multiple range tests results for RFS_{before} of illumination conditions

Floor	Mean RFS_{before}	Duncan's grouping
Light	4.45	A
Dark	3.85	B

The ANOVA results of the RFS_{after} indicate that the following effects were significant: floor (p<0.0001), surface (p<0.001), shoes × floor (p<0.05), floor × surface (p<0.01), and shoes × floor ×surface (p<0.05). The effects of shoes were not significant. Neither were the effects of illumination significant. The Duncan's multiple range test results for the floor and surface are shown in Table 5 and 6.

Table 5: Duncan's multiple range tests results for RFS_{after} of floor conditions

Floor	Mean RFS_{before}	Duncan's grouping
C1	4.86	A
C2	4.70	A
Granite	3.84	B

Table 6: Duncan's multiple range tests results forRFS_{after} of surface conditions

Floor	Mean RFS_{before}	Duncan's grouping
Dry	4.64	A
Wet	4.51	A
Detergent	4.26	B

The ANOVA results of the PSOSindicate that the following effects were significant: shoes (p<0.01), floor (p<0.0001), surface (p<0.0001), shoes ×floor (p<0.0001), shoes ×surface (p<0.0001), floor ×surface (p<0.0001), shoes ×floor ×surface (p<0.0001). The effects of illumination were not significant. The Duncan's multiple range test results for the shoes, floor, and surface conditions are shown in Table 7, 8, and 9.

Table 7: Duncan's multiple range tests results for PSOS of shoes conditions

Shoes	Mean PSOS	Duncan's grouping
Rubber	0.74	A
EVA	0.45	B

Table 8: Duncan's multiple range tests results for PSOS of floor conditions

Floor	Mean PSOS	Duncan's grouping
Granite	1.51	A
C2	0.20	B
C1	0.08	B

Table 9 Duncan's multiple range tests results for PSOS of surface conditions

Surface	Mean PSOS	Duncan's grouping
Detergent	1.31	A
Wet	0.29	B
Dry	0.18	B

4. DISCUSSION

Illumination was an important factor to be considered. The light condition was one that represents the ordinary daylight condition. The dark condition was manipulated by blocking the sunlight into the laboratory using curtains on all windows. The RFS_{before} was the rating of floor slipperiness based on visual judgment. Illumination was, therefore, believed to be a significant factor affecting this variable. This was supported by our ANOVA results that illuminationwas significant (p<0.0001) on the $RFS_{before.}$ On light illumination conditions, the subjects gave a significant (p<0.05) higher RFS_{before}. than that of the dark condition. The theoretical basis is quite simple. The subjects were reluctant to give a NOT SLIPPERY rating when they couldn't see clearly the walkway. For the RFS_{after}, illumination was, on the other hand, not a significant factor. The subjects gave their ratings of floor slipperiness based on their perception during the gait. Such a perception was mainly determined by the traction of their foot on the floor. Illumination, therefore, became a minor factor.

Chiou et al. (2000) proposed the PSOS to indicate the risk of slip & fall when walking. The final PSOS was the addition of the ratings of the four questions. High PSOS indicates high risk of slip and fall. As each of the response of the question is in the range of 0 to 2, the final PSOS is between 0 to 8. Chiou et al. (2000) indicated that a fall will occur if the PSOS exceeds 4.5.The PSOS ranged from 0 to 6. However, most of the PSOS values were 1.0 or lower. This implies that the overall risk of slip and fall in our experiment was low. Even though the PSOS difference between the rubber and EVA was significant (p<0.05), the means of both footwear were lower than 1, indicating low slip & fall risk. For the floors, the PSOS of granite (1.51) was significantly higher than those of C1 (0.08) and C2 (0.20). This implies that the granite floor provided higher risk of slip and fall than the other two floors. For the surface conditions, the PSOS of the detergent condition (1.31) was significantly (p<0.05) higher than those of the wet (0.29) and dry (0.18) surface conditions. The subjects certainly perceived higher risk of slip and fall when they were walking on detergent contaminated surfaces than those of the wet and dry surfaces. Figure 5 shows that the highest PSOS was observed at the detergent solution covered granite floor when rubber shoes were worn. The mean PSOS was approximately 5, a level that slip and fall was believed to occur with certainty. The low PSOS values of the wet surfaces were unexpected as the shoe soles of both of the lab shoes were flat without tread.

5. CONCLUSION

A gait experiment was conducted to test the subjective ratings of human subjects concerning their perception on floor slipperiness. It was found that the perceived floor slipperiness before the gait was affected significantly by illumination, floor, and surface conditions. The perceived floor slipperiness after the gait was significantly affected by shoes, floor, and surface conditions. Illumination was a significant factor only before the gait. The PSOS was significantly affected by shoes, floor, and surface conditions.

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